Calibrating SNAP

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ABSTRACT

The SNAP (Supernova / Acceleration Probe) mission's primary science goal is the determination of the properties of the dark energy. Specifically, observations of distant Type Ia supernovae will be used to measure the dark energy equation of state constant parameter, w_0, and time varying parameter, w_1, to a fractional uncertainty of 0.05 and 0.3 respectively. This places stringent requirements on the control of systematics and on the absolute color calibration of these supernovae. The overall calibration for the SNAP CCD and NIR imagers and spectrograph will be conducted through several routes. We envision employing a variety of well-studied stars, certainly including the HST spectrophotometric standard stars (and possibly the Sun) and performing indirect transfer calibrations that permit comparison with NIST irradiance standards to close the loop with fundamental MKS quantities. We discuss the basic issues and possible strategies in order to achieve ~2-3% color errors over the wavelength range of from 350 to 1700 nm.

Keywords: spectrophotometric calibration, standard stars

1. INTRODUCTION

The Supernova / Acceleration Probe (SNAP) is a proposed space-borne mission that will measure the anomalous acceleration of the universe by observing the luminosity distances and redshifts of Type Ia supernovae out to a redshift of z=1.7. The SNAP observatory is designed to for a Delta IV fairing and consists of a three-mirror anastigmat with a 2-m aperture. Its focal plane array is an annulus containing 36 near infrared (NIR) (HgCdTe) detectors and 36 CCDs with nine filters, six in the optical and three in the NIR. The field of view is 0.67 square degrees. The two-channel, integral field unit spectrograph has an entrance aperture of 3 X 3 arcseconds.

SNAP's primary science goal is to understand the expansion history of the universe. In particular, observations of several thousand Type Ia supernovae (SNe Ia) with redshifts up to z = 1.7 will be used to determine the constant and time varying equation of state parameters w_0 to 0.05 and w_1 to 0.3. This specification places stringent requirements on the control of systematics and on the absolute color calibration of SNe Ia. The detailed spectral response function of each broad filter bandpass must be known accurately to correct systematic photometry offsets induced by redshift (the "K-correction") and the time variable supernova spectral energy distribution. Although SNe Ia are all nearly identical, their photometric properties vary with both time and redshift making an accurate global color calibration essential. In practice, a color calibration better than 2-3% over the wavelength range from 350 to 1700 nm is required. On orbit observations of spectrophotometric standards, including HST (Hubble Space Telescope) standards, and possibly the Sun, can be used. In the near infrared, new comparisons against NIST irradiance standards will likely be needed to generate calibrated standard stars.

2. SPECTROPHOTOMETRIC CALIBRATION

To place a supernova on the Hubble diagram we need to know its redshift and its true apparent magnitude. In the absence of an intervening medium, the measured rest-frame brightness of an object would depend only on its distance. However, light from astrophysical objects is dimmed and reddened by dust along the light of sight: in the host galaxy, in the intergalactic medium and in the Milky Way galaxy. This extinction is commonly measured as a difference between the intrinsic and observed colors of the target object where color is the ratio of luminous flux (measured as a difference in magnitudes) in two bandpasses. Errors in the photometric zero point will also affect the measured brightness. The zero point in magnitudes for each filter plus detector or spectrograph channel is determined though observations of previously calibrated spectrophotometeric standard stars. Thus

$$m_{true} = m_{measured} - zeropoint - extinction$$

where m is the apparent brightness in magnitudes; the zeropoint and extinction units are also magnitudes. For a distant Type Ia supernovae, where the apparent redshifted B-band is observed, this becomes

$$m_{true} = m_{B(z+1)} - zeropoint_{B(z+1)} - extinction_{MilkyWay} - extinction_{HostGalaxy}$$

where z is the supernova redshift and the B(z+1) is the observed bandpass into which the supernova rest frame B-band is redshifted. Thus calibration errors enter twice – first in the determination of the zero point and then again in the extinction measurement. It is therefore important to control precisely the absolute color calibration.

2.1 Determination of Calibration Errors: General Formalism

The essence of calibration is to determine the response R(λ) or sensitivity S(λ) with respect to wavelength of the instrument, e.g. a telescope plus detector system. This is done by observing a light source whose specific intensity is known – for example, a NIST traceable light source-- with the same experimental instrument. Once the sensitivity is measured, the flux (erg cm^{-2} s^{-1} nm^{-1}) from any other source can be determined.

The flux of the calibrated light source (which can be a black body furnace, a tungsten lamp and/or a star) as detected at the experimental telescope is

$$F_{lamp}(\lambda) \propto I_{lamp}(\lambda)$$

where I is the specific intensity. The sensitivity of the instrument is

$$S(\lambda) = \frac{F_{lamp}(\lambda)}{R_{lamp}(\lambda)}$$

where R is the measured counts at the detector. Once S(λ) is known, then the flux of any other light source is related through the number of counts and the sensitivity:

$$F_{star}(\lambda) = R_{star}(\lambda) S(\lambda).$$

The science requirements for SNAP demand that the error in color, i.e. the *slope* or first derivative of this relation:

$$\frac{dF(\lambda)}{d\lambda} = \frac{d}{d\lambda}\left(S(\lambda)R(\lambda)\right)$$

have an uncertainty, $\sigma \leq 0.03$, from the bluest bandpasses at ~350 nm to the reddest at 1700 nm. For a star of flux F_{star} the error in the star's color is proportional to the error in the original determination of the sensitivity, i.e.

$$\frac{dFstar(\lambda)}{d\lambda} = \frac{d}{d\lambda}\left(\frac{F_{lamp}(\lambda)}{R_{lamp}(\lambda)} R_{star}(\lambda)\right).$$

The uncertainty in the sensitivity is proportional to the uncertainty in the measurement of the calibrating light source flux incident on the detector and on the geometry of the experiment. If the calibrating light source is a black body, e.g. platinum at the melting point, the uncertainty in the temperature will be dominant. If the light source is a star, for example, a white dwarf or the sun, the uncertainty will depend on the input physics of the model atmosphere, primarily temperature and surface gravity, but also metallicity. Typically, however, due to limitations of dynamic range blackbodies and stellar models plus observed spectra are used in a several step process. Thus the final uncertainty in the slope (color) is the sum of the uncertainties at each step: where *i* is the number of steps and $\sigma_i^2 = \sigma_{dF_i}^2 + \sigma_{dR_{i\,i}}^2$. The practical application of these general principles for the SNAP calibration is discussed in section 3 below and shown as a flowchart in Figure 1.

The flowchart in Figure 1 is essentially a decision tree depicting the relationship between systematic errors in the color calibration and the type of calibration program that would be required to meet the calibration requirement. If the current stellar atmosphere models are well understood, i.e. the physics is well constrained and the models exactly match real stars, then the models effectively calibrate the standard stars. However, if these models fail at a level of uncertainty that is greater than the requirements, then they need to be calibrated against a standard e.g. Vega (bottom of the leftmost column). If after this step is applied, the systematic errors are too large, then it becomes necessary to "recalibrate" the calibrator – Vega. (middle column). This effectively means calibrating Vega or another star against a known irradiance standard, e.g. a NIST certified blackbody (Hayes 1970, Hayes and Latham 1975, Hayes, Latham, and Hayes 1975). Observations of the star may be carried out using ground-based telescopes, however, if the systematic uncertainties (mostly due to the Earth's atmosphere) cannot be minimized, it may then be necessary to devise a balloon- or space-based experiment (rightmost column). In the event that the calibration requirements cannot be met at all, then the impact on the science of revising the calibration specifications must be addressed.

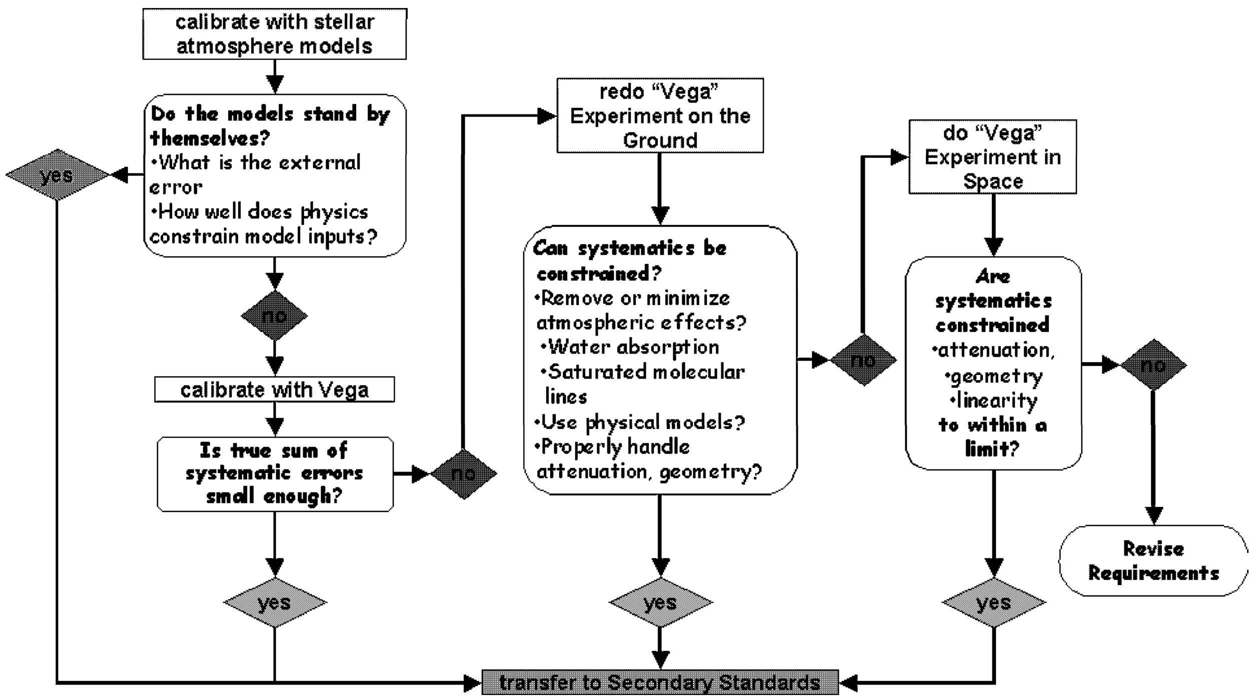

Figure 1. This flowchart shows the relationship between systematic errors in the color calibration and the type of calibration program that would be required. The term "Vega" experiment is used here to refer to the process by which an astrophysical source's flux is tied to an irradiance standard.

3. THE SNAP SPECTROPHOTOMETRIC CALIBRATION PLAN

The spectrophotometric calibration for the SNAP mission will be conducted through several routes. We envision employing a variety of well-studied stars, including the HST spectrophotometric standard stars (and possibly the Sun), to establish a standard star network and performing indirect transfer calibrations that permit comparison with NIST irradiance standards to close the loop with fundamental MKS quantities.

3.1 The SNAP Standard Star Network

In order to minimize the need for on-orbit calibration time, a ground-based standard star network consisting of fundamental standards, primary standards and secondary standards will be established. This network will provide the preliminary calibration data for spacecraft by setting the spectrophotometric zero points and identifying candidate standard stars and variable stars (to exclude) in the SNAP fields. Further, the network will enable parallel and follow-on observation from the ground to support on-orbit science observations.

The goal of the program is to establish a system of well-characterized standard stars in each of the SNAP North (SNAP-N) and South (SNAP-S) pointings, with several standards placed in the weak lens survey fields and in fields around the celestial equator. These latter fields would be used initially to tie the northern and southern SNAP fields together, but expansion to cover the entire 24 hours of the equator will ensure standards are always accessible for ground-based observation from both hemispheres.

We have defined the following terms after the nomenclature of the Sloan Digital Sky Survey (SDSS) standard star network (Smith et al 2002). Fundamental standards will be limited to a few spectrophotometric standard stars, which will be used to define the filter zero points. These stars will be referenced back to irradiance standard, for example a NIST lamp and reference to a well-characterized spectrophotometric standard star, e.g. Vega. Fundamental standard stars will likely be hot white dwarfs like G191-B2B or solar analog stars. Primary standards will be fainter than the fundamental standards, and will be calibrated with respect to the fundamental standards. They will be used to transfer the zero points to an "all sky" grid. These stars will consist of white dwarfs, solar analog stars, metal poor sub dwarfs and K giants which may be in the SNAP science fields. Secondary standards will be in the SNAP fields and shall be used for direct calibration of the data obtained by the spacecraft. They will span a wide color and magnitude range, and hence spectral type, and will be calibrated against the primary standards.

Establishing the fundamental standards by comparison to existing flux standards – NIST lamps, spectrophotometric stars or models, is a priority. A possible set of fundamental standards is the current Hubble Space Telescope standard stars, two white dwarfs and two solar analogs all of which are between 11 and 13 magnitudes. These will be transferred to the primary standards via direct spectrophotomery, photometry and modeling. Uncertainties will be minimized by repeated ground-based measurements and end-to-end observations (throughout the year). The fainter primary standards will then be tied to the secondary standards through spectrophotometry and photometery. Again, uncertainties will be minimized by multiple observations of the fields. Once in orbit, we will verify the zero points for both the primary and the secondary standard stars. The planned, repeating observation cadences will allow typically 121 observations of every star in the SNAP-N and SNAP-S field over the course of the mission, leading to refinement of the brighter secondaries and establishment and verification of the fainter secondaries.

The challenge is to establish an all sky photometric system covering the spectrum from 350 to 1700 nm and spanning approximately 6 magnitudes (12 to 18 mag) of brightness to an accuracy of about 1%. This should allow the science requirement of 2-3% in the color to be achieved. Uncertainties in the standard star network will take up to one half of the total error budget for the program.

3.2 Calibration Strategies

A key objective in the acquisition of SNAP fundamental calibration standards is to determine accurately the spectral shape of a set of calibration stars. Here we discuss two strategies for the acquisition of the fundamental calibration stars to the accuracy required by the SNAP science, namely a) using existing HST reference stars and b) measuring a new set of bright flux standards. These strategies are based on accurate spectrophotometer measurements of the spectral shape of well-characterized flux standard stars above the atmosphere. Once the spectral shapes of the fundamental calibrators have been determined, the calibration is transferred to the primary standards and to the secondary standards in the SNAP fields. With this set of calibration standards in the SNAP fields, precision absolute color photometry of supernovae can be obtained.

In the first approach, SNAP adopts the white dwarf/solar analog standards used by HST. This strategy is clearly the simplest, but it leads to the largest errors in the near infrared. In the second approach, bright calibration standard stars are measured with a balloon-borne telescope/spectrometer that has been accurately calibrated with a NIST lamp. Calibration is then transferred to the standard star network through two steps to the primary SNAP calibrators and the errors in the spectral shape are directly traceable to a NIST lamp over the full 350-1,700 nm SNAP wavelength range. In addition, the spectral shape of the calibration standards becomes independent of any changes to the SNAP instruments that might occur during and after launch. It should be noted, however, that none of the plans described here uses ground-based observations for the fundamental calibrators. There are several reasons for this. Most important is the problem of deconvolving the varying atmospheric spectral shape from the stellar spectral shape, a consideration particularly important in the near infrared where water vapor opacity is significant. While atmospheric absorption is a smooth function at wavelengths bluer of ~800nm, there are three major absorption bands centered at 900 nm, 1.1 μm and 1.4 μm.

As shown by Bernstein (2002) and Linder and Huterer (2003) Type Ia supernovae at redshifts greater than z ~ 1 provide the greatest power to discriminate among cosmological models, as is shown in Figure 2. At these redshifts the bright restframe B-band is shifted into the near infrared. Thus, distant supernovae are best discovered at these wavelengths. SNAP's principal advantage over ground-based experiments is its near infrared capabilities. This strongly suggests that it is essential to calibrate SNAP well in the near infrared.

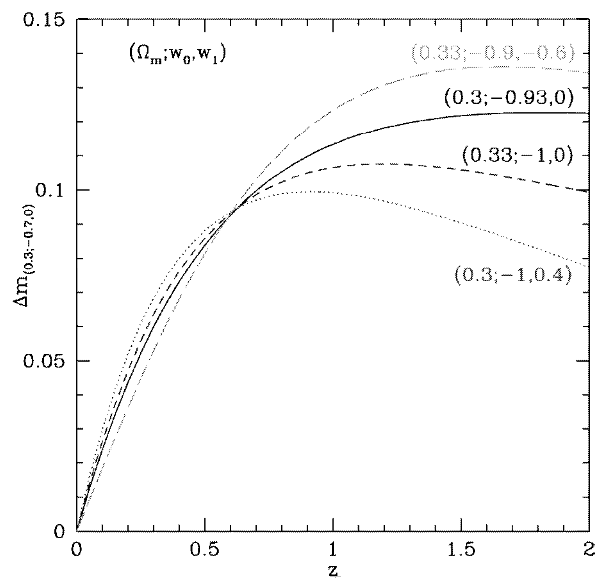

Figure 2. This Hubble diagram shows four models with similar values for the mass density $\Omega_M \approx 0.3$ but different equation of state parameters. Redshift is plotted along the abscissa and the ordinate is the difference in magnitudes of the models relative to a fiducial cosmology with matter density, $\Omega_M = 0.3$, and a constant parameter, $w_0 = 0.7$, and $w_l = 0$. The upper (long dashed line) model has $w_0 = -0.9$,.$w_l = -0.6$, the second model (solid line) has $w_0 = -0.93$, $w_l = 0$, the third (short dashed line) has $w_0 = -1$, $w_l = 0$, and the lowest model (dotted line) has $w_0 = -1.0$, $w_l = 0.4$. Differences between models are greatest at redshifts greater than z~1. (Figure courtesy of Eric Linder.)

Absolute spectrophotometric calibration in the optical and near infrared has been carried out on the ground for several stars, most notably Vega (cf. Megessier 1995). HST's calibration is based on a combination of models and spectroscopy of four stars: two white dwarfs and two solar analogs, fixed to Landolt V band photometry (Colina & Bohlin 1994, 1995; Bohlin, Dickinson and Calzetti 2001). The Sloan Digital Sky Survey (SDSS) developed its own calibration program based on one primary standard star whose spectrophotometry traces back to the absolute calibration of Vega (Smith et al 2002). The SDSS network of optical secondary standards was developed with a three-telescope program using a 0.5m, a 1.0m and a 2.5m (the Sloan telescope itself) in order to span the required dynamic range in brightness from the bright primary standards to the faintest secondaries. The SDSS requirements limit the internal errors in the photometry to 0.02 magnitudes and in the optical colors (e.g. u'-g', g'-r', r'-i', i'-z') less than 0.03 magnitudes. (http://www.astro.princeton.edu/PBOOK/photcal). The achieved accuracy is less than 0.01 mag in r' and 0.015 mag in the colors (< 1.5% in g', r', i' and < 3% u' and z') (Smith et al 2002).

SNAP is a space observatory, requiring a similar network of standard stars in the SNAP filters but with a longer wavelength reach – from 350 nm to 1700 nm. There are several choices for establishing SNAP's own network. The first is carrying out a program from the ground. However, the atmosphere's many absorption bands in the near infrared may vitiate the reliability of the planned NIR bandpasses. The second option is a space program, perhaps using SNAP itself, which bypasses atmospheric effects. Other options include a mix of ground, space and balloon platforms. The total cost and schedule of the color calibration program depend on the choice of platform(s).

3.3 HST Standards as Fundamental Standards

In the HST approach to calibration, multiple spectrophotometric measurements of stable white dwarf stars are fit to pure hydrogen, non-LTE (local thermodynamic equilibrium) stellar atmosphere models and those of the solar analog stars are fit to non-LTE models (Bohlin *et al.* 2001). This fitting procedure normalizes the spectral shape. Matching synthetic V-band measurements to measured Landolt V magnitudes for each of these stars sets the flux scale. By choosing to set the flux scale with ground-based V measurements, the effect of atmospheric opacity corrections on the spectral shape are minimized. The self-consistent calibration chain of comparing white dwarf spectrophotometry to white dwarf models yields 1% errors in the optical broadband magnitudes. However this procedure leads to errors in the near infrared that are considerably larger than 1%. At present there are only two primary NICMOS standards: the white dwarf G191B2B and the solar analog star P330E (Bohlin *et al.* 2001). Although the internal errors in the synthetic near infrared magnitudes computed from white dwarf model atmospheres are also ~1%, the near infrared flux scale, when compared with the flux scale established for P330E, leads to differences that are 2.5-3 times larger than this.

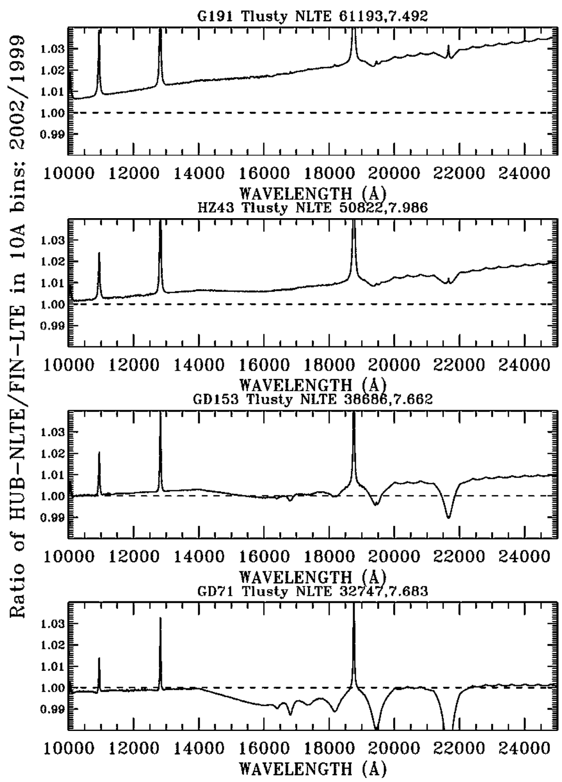

Figure 3. Comparison of Hubeny non-LTE (Hubeny et al 1999) models versus Finley LTE (Finley et al 1997) models of white dwarf stellar atmosphere for four white dwarf calibration standards. Plotted on the horizontal axis is wavelength in angstroms, the vertical axis is the percent difference between the models. G191B2B (top spectrum) is the HST NICMOS standard.

Presently there are discrepancies in the stellar atmosphere models in the near infrared that add additional uncertainty to the spectral shape and that are harder to quantify. Figure 3 shows this quite clearly. Plotted in the figure is the comparison of Hubeny NLTE to Finley LTE models for each of these white dwarfs. The models produce the same flux ratio between 500 and 600 nm, but differ significantly from each other in the near infrared. The primary NICMOS standard G191B2B is at the top of the figure.

The issue for SNAP is whether the current discrepancies between models and NICMOS data will show enough improvement in the near infrared (now that NICMOS is back online) so that the SNAP science goals can be achieved with HST standards. The answer to this question is not clear because the SNAP science requirement on the precision of the near infrared photometry has not yet been determined. However, if an in-band uncertainty of 1%-2% is adopted as the requirement, it is likely that NICMOS will not validate the models sufficiently. A conclusion from Bohlin *et al.* (2001) is : "In order to improve the accuracy of the standard star IR flux distributions, some standard stars should be compared to an actual standard IR lamp to define a proper absolute flux calibration, just as was done for Vega. … such fundamental data are lacking…" Since Bohlin *et al.* normalize the flux scale at one bandpass once the spectral shape has been determined; the lamp comparison is required to improve the spectral shape of the models.

The advantages of using stellar atmosphere models to normalize the SNAP fundamental standards are twofold. First, this is a tested method that yields relatively high precision colors, particularly in the optical although much less so in the near infrared. Second, this method has been shown to reduce errors in broadband magnitudes to 1% in the optical. Disadvantages of this approach are that systematic errors in the models are difficult to quantify and are not traceable. Current uncertainties in the broadband near infrared magnitudes are 2.5-3%, without accounting for systematic errors in the models; to reduce errors, more sophisticated models need to be constructed and compared with a lamp source. In the near infrared, the flux scales of the white dwarfs are not consistent with the solar analogs.

3.4 Using Balloon-Based Calibrations

In the second approach to calibration, measurements of fundamental standard stars are made relative to a NIST-calibrated lamp with a balloon-borne telescope/spectrometer that flies above 99.9% of the atmospheric water vapor. This measurement-based approach defines the spectral shape of the primary calibration standards with respect to the NIST lamp and the calibration errors are directly traceable to it.

The balloon-based calibration plan is designed to accurately compare the irradiance of a NIST lamp, $f_{lamp}(\Delta\lambda)$, with the irradiance of the calibration star, $f_{star}(\Delta\lambda)$, over each spectrometer resolution element $\Delta\lambda$, where

$$f_{lamp}(\Delta\lambda) = \iint_{\Delta\lambda,\Delta\Omega} F_{lamp}(\lambda,\Omega)S(\lambda)d\lambda d\Omega,$$

$$f_{star}(\Delta\lambda) = \iint_{\Delta\lambda,\Delta\Omega} F_{star}(\lambda,\Omega)S(\lambda)d\lambda d\Omega.$$

Here $F_{lamp}(\lambda,\Omega)$ and $F_{star}(\lambda,\Omega)$ are the radiances of the NIST lamp and the fundamental calibration standard star, respectively; $S(\lambda)$ is the response function of the telescope/spectrometer; and $\Delta\Omega$ is the solid angle seen by the detector . Key to this scheme is the accurate calibration of the telescope/spectrometer. Careful measurements of $f_{lamp}(\Delta\lambda)$ with a NIST calibrated lamp in a facility built with optical components accurately calibrated by NIST allow the characterization of $S(\lambda)$ to very high precision. Measurements of $f_{star}(\Delta\lambda)$ then yield high precision values of $F_{star}(\lambda,\Omega)$ with uncertainties directly traceable to the NIST lamp. The values of $F_{star}(\lambda,\Omega)$ give accurate broadband magnitudes.

Two issues play a central role in this approach to calibration. First, the dominant background for these balloon-based measurements in the near infrared is bright OH emission originating at 80-100 miles, well above the altitude reached by a balloon. Therefore, to achieve the S/N required in the presence of the bright OH background during the limited time available on a balloon flight demands bright program stars. However, stars bright enough to be calibrated from a balloon are too bright to be observed by SNAP. Consequently, the calibration must be subsequently transferred from the bright program stars to the fainter stars from the ground. We believe this transfer can be accomplished in two transfer steps: from a V=5 K0III star to a V=12 K0III star, and (2) from a V=12 K0III star to the V=16 SNAP primary calibration standard stars. Second, the NIST 1 kW FEL lamp required for the calibration of the telescope and spectrometer is 10-12 orders of magnitude brighter than the 5th magnitude program stars, the brightness at which the telescope/spectrometer must be calibrated. What this means is shown below in Figure 4.

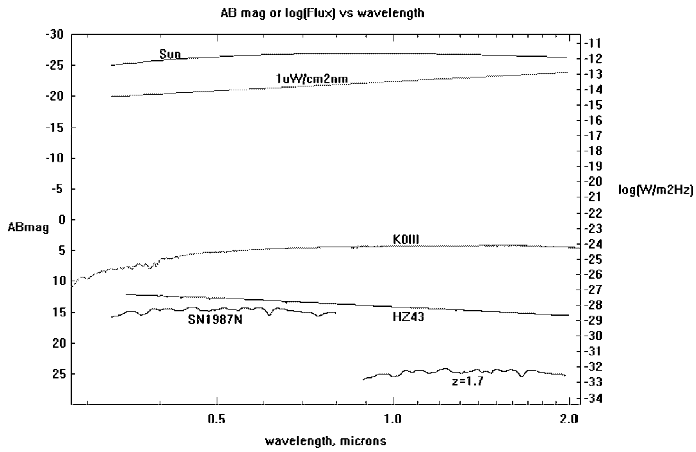

Figure 4. Shown in this figure are a comparison of the brightness, in magnitudes on the left axis and in $W\text{-}m^{-2}Hz^{-1}$ on the right axis,of several astronomical sources and a NIST blackbody, the second curve from the top. The spectra of the sun, a V=5 K0III star, a bright white dwarf calibrator (HZ43), and two schematic supernova light curves at z=0 (SN 1987N) and z=1.7 are also shown. There is a factor of 10^{19} between the brightness of a distant supernova and a very nearby FEL light source.

The telescope/spectrometer is carefully calibrated on the ground using a calibrated, collimated beam that overfills the telescope primary. The collimated beam is calibrated first, then the telescope as in Figure 5 below. The right hand side of the figure is the apparatus that attenuates the NIST lamp to the appropriate brightness (using a combination of an integrating sphere, a precision aperture, and neutral density filter) and collimates the beam. Using an off-axis collimator minimizes scattered light problems. The entire setup is enclosed in a dry, thermally controlled chamber.

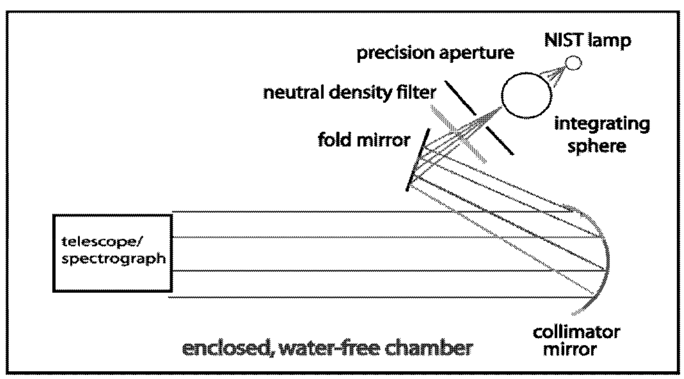

Figure 5. Setup for calibrating telescope plus spectrograph with a collimated beam. The instrument on the right hand side of the figure – lamp, integrating sphere, filter, fold and collimator mirror are calibrated before hand in the same chamber, where the calibrator replaces the telescope plus spectrograph on the left hand side.

There are two primary strengths of this calibration scheme. First, the calibration is measurement-based and is independent of stellar atmosphere models with traceable errors propagated from the NIST calibrated source, and measurements are independent of atmospheric corrections. Second, the calibration is independent of SNAP. Changes to SNAP during launch do not affect the calibration since SNAP is calibrated by observing the well-characterized primary standards once it reaches orbit. On the other hand, this is a technically challenging experiment.

3.5 Transfer Accuracy to Fainter Stars

A preliminary Monte Carlo analysis of the balloon-based calibration route propagates the fluxes from a V = 5 KIII program star to a V =16 secondary standard and keeps the error budget below 1%. The transfers begin with the fundamental standards as determined by the absolute-calibrated balloon payload, and extend through several stages to reach stars as faint as 16th magnitude, at which point SNAP itself would be used. The simulation assumes the balloon telescope is a 15-inch Ritchey-Chretien telescope with a two channel (optical, near-IR) spectrometer (R = 150) that switches between (star+sky)/sky and (star+sky)/NIST lamp, and a plate scale of 30 arcsec/mm. The comparison lamp is a NIST standard 1kW commercially available lamp. In these calculations it is assumed that the irradiance of the lamp has been reduced by geometry in a wavelength independent way. Although the systematic errors in reducing the irradiance of the lamp have been included in the computations, these errors should be unimportant if only relative flux calibrations are important. For the star observations, sky background was taken from Leinert et al (1988). OH emission, zodiacal light and faint star emission were included in the near infrared airglow; O_2, zodiacal light, and faint star emission were included in the diffuse night sky brightness.

The errors in the transfer from NIST lamp to K0III star have been computed based on 600 Monte Carlo realizations of the proposed experiment. The statistic chosen as a measure of the errors is ($B-B_0$) and ($J-J_0$) where B_0 and J_0 are the B and J magnitude without error. Systematic and statistical errors have been propagated from the NIST lamp to the calibration star wavelength bin-by-wavelength bin and the magnitudes computed using standard wide-band filters. The offset in the mean of the lamp and primary calibration star is due to the error in reducing the lamp irradiance. The results are shown in Table 1.

	K0III	White Dwarf T=38,000 K	White Dwarf T=50,000 K
$B_{T2} - B_0$	.0052	.0060	.0060
$(B-V)_{T2} - (B-V)_0$	.0076	.0088	.0087
$(B-J)_{T2} - (B-J)_0$	.0088	.012	.012
$(B-H)_{T2} - (B-H)_0$	.0087	.012	.013

Table 1 Transfer of calibration from a lamp to three 16th magnitude standard stars in two steps. The first row shows the error in the B band, the next three rows give the errors in each of three colors: B-V in the optical and in the near infrared, B-J and B-H .

Presently a similar study of the equivalent transfer of errors from the HST standards to the fainter secondary standards in the SNAP fields is being conducted.

4. CONCLUSIONS

The SNAP spectrophotometric calibration plan described here, and the preliminary calculations suggest that 1% relative spectrophotometric accuracy propagated from a NIST blackbody can be achieved for stars as faint as V = 16 magnitude. And thus that we can meet the science requirements of absolute color calibration over the 0.35 to 1.7 micron wavelength range of SNAP of 2-3%.

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